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HANDLING OF APPLES DURING SORTING-GRADING OPERATION AND MEASURING THE MECHANICAL PROPERTIES FIRMNESS AFTER CONTROLLED ATMOSPHERE STORAGE

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ABSTRACT

Apples are very sensitive to surface damage during post-harvest operations and transportation. Any mis-handling can affect the texture and crunchiness thereby the shelf life of apples. Experiments were conducted to reduce mechanical damages during sorting-grading operations by installing a water tank at the feeding conveyer of sorting-grading machine. Four varieties of apples, Viz. Royal Delicious, Red Delicious, Rich-a-Red and Golden Delicious (of Himachal Pradesh, India) were studied for bruising effects by comparing handling techniques of manual unloading to the conveyer or to water handling system. After sorting-grading operation, apples were stored in controlled atmosphere storage (CAS) at a temperature of 1^0C, 90-95% RH, 1 to 2% oxygen and 0.5 to 1% carbon di-oxide levels. Conventionally apples are packed in corrugated fiber board (CFB) boxes in the orchard level. From the orchards, apples are transported to the storage points, where pre-storage operations like sorting-grading and bin filling are done. When apples are unloaded manually from CFB boxes to the sorting-grading machine conveyer, several mechanical damages, even though appear minor, cause firmness loss on post-storage. A new technique is used to unload apples from the CFB boxes into a water tank, from where the sorting-grading feeding conveyer picks the apples for further processing. This experiment resulted in better firm apples during shelf life period, i. e. after storage of apples for two months in CAS. Better apple firmness is found in all the four varieties with water unloading technique compared to manually unloaded apples.

KEYWORDS: ***Food Security, Apple, Mechanical Damage, Firmness Loss, Sorting-Grading, Bruising & Controlled Atmosphere Storage***

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Original Article

INTRODUCTION

Apples are grown only in a suitable climate, geographic region and season. Several preservation methods like pre-cooling, cool store, drying, etc. are used to preserve apples to benefit farmers to get a good price while selling [1]. Several researchers investigated on the cooling aspects and heat and mass transfer to remove field heat of fruits by forced air cooling [2], hydraircooling [3-5] Cold Storage (CS) or Controlled Atmosphere Storage (CAS) is used to store fruits and vegetables for longer periods [6-7]. In the CS, fruits are cooled to low temperature and maintained at that temperature to increase its life. In CAS, fruits are kept at low oxygen and high carbon dioxide level apart from low temperature and high relative humidity.

The important processing operations carried before apple storage are: sorting, quality, segregation, size grading, colour grading and filling into the storage bins (either wooden or plastic perforated bins) [8]. Sorting indicates separating the non-storable fruits from the best fruits. Non-storable fruits include: Over matured/ripened, heavily bruised, spoiled/damaged due to mis-handling during plucking or transportation or insect damaged fruits. Grading means segregating the fruits based on the size and colour. Different varieties and sizes of apples [9] are stored in separate storage chambers due to the fundamental difference in the rate of respiration and ethylene generation [10-12]. This may help to get an optimum shelf life. From the preliminary experiments, it was found that large sized fruit firmness last for a short time and small sized fruit firmness last for a long time during storage with a post-storage firmness of 12-14 lbs approximately. However, this depends on the type, variety, pre-harvest practices and origin of the apples.

Quality segregation includes separating the apples, which are not storable or to be disposed off to the market immediately without storing. Segregation of apples on the basis of quality evaluation is done by using simple chemical and physical tests [13]. The Maturity index, Total soluble solids (TSS) and Firmness are the most commonly determined and well acceptable parameters to assess the quality being simple quick and easy to test among physico-chemical properties. Mechanical parameters like texture profile analysis, dynamic mechanical analysis and Visco-elastic properties give deep insight. However, these are not suitable for field applications and/or time consuming and helpful for detailed research [14].

Traditionally, the apples are stored at low temperature in CFB boxes or plastic bins/ crates. Some storage plants in India use large capacity plastic bins (300 kg cap) for storage. In the present project this kind of bins is used. Proper handling of fruits using mechanized conveyers and sorting-grading machines with rubber conveyer belts make smooth and damage free handling of fruits during sorting-grading operation and lead to better the life of the fruits up to 8 to 10 months.

Several physico-chemical changes occur during storage and post-storage of fruits [15-16]. Firmness is one of the most important measurable quality parameter from a consumer point of view. Firmness is measured with a Penetrometer. Firmness is expressed in pounds (Lbs). Crunchiness and crispiness are the terms used for expressing the quality of apple.

These two indicate the textural characteristic, whether the apple is mealy (soft) or crunchy. Approximate firmness range of 20 to 22 pounds is found in the fresh apples of optimum maturity at harvest point/orchards. Firmness values decrease as the apple ripening progresses with respect to time. Ripening occurs due to respiration and metabolic activities [12]. Apples below 10 Lbs are termed as mealy/soft textured.

The present study is undertaken in the Controlled Atmosphere storage complex in Rai, Haryana, India. The handling (sorting, grading and bin filling) capacity of the plant is 200 Metric Tons (MT) per day and the storage capacity of the plant is 12000 MT. The plant is designed with 78 chambers of 150 MT capacity each. To carry the

pre-processing operations, the facility is equipped with sorting-grading machine installed in a temperature controlled processing hall of 75 m x 20 m space adjacent to the storage chambers.

Apples received at the entrance of the sorting-grading hall are first unloaded through the dock shelter, moved to sorting-grading machine by using power-pallet truck, sorted-graded and filled into the bins and then moved to the storage chambers using electric forklifts. Apples are procured in 20 kg capacity CFB boxes from Himachal Pradesh, India. Transferring of apples from the CFB boxes to the sorting-grading machine is done by a large number of unskilled labour to match the capacity of the sorting-grading machine. During this handling, it was found that apples are dropped into conveyer instead of 'placing' on to the conveyer. This causes mechanical bruising. So there is a need to reduce the bruising which is affecting the firmness/crunchiness thereby improve the consumer acceptance.

LITERATURE OVERVIEW

Billy et al. (2008) [10] investigated on the texture of two apple cultivars for five storage periods comparing instrumental and sensory methods. They explained apple texture changes with different measurements of physical and chemical measurements. Physical measurements were done with Penetrometer and compression test. Chemical measurements were done by pectin composition analysis. They obtained positive correlation between mealiness and galacturonic acid content. Observed sensory crunchiness and firmness measured with instrument were negatively correlated.

Brizzolara et al. (2017) [17] Conducted experiments to characterize the apple (Red delicious-RD and Granny smith-GS) metabolic changed under low oxygen and dynamic CA conditions for 200 and 214 days storage for Gs and RD respectively. No significant differences were found between the samples of the same variety at the storage period end in firmness, Titrable acidity and TSS. Significant differences were imposed from the report of metabolic profiles. Costa et al. (2012) [18] Carried investigations on 83 cultivars for two months in the cold storage to study the texture parameters. Dynamics of textural components highlighted the storage index, suggesting that texture postharvest physiology is unique. They have concluded that fruit texture is the result of cell wall/middle lamella undergone modifications during ripening. They also concluded into two categories of mechanical and acoustic in respect of texture based on the degrading enzymes.

Costa (2016) [19] has thoroughly investigated on wound causing quality decay and loss of apples due to mechanical handling and transportation. They used a texture analyzer to find the contribution of peel on the fruit firmness of the apple. 65 accessions of germplasms were checked for a two month period in a cold storage. They analyse the intact and peeled portions on each fruit and characterized the peel contribution on firmness. They proposed the characteristics as novel traits, going to be useful for breeding and better mechanical performance of peel and enhanced postharvest potential.

Gwanpua et al. (2014) [20] have studied Jonagold apple (Malus domestica Borkh) for the softening behaviour. They studied postharvest ripening through the pectin modifications and pectin-modifying enzymes. Commercial matured apples were stored at different temperatures and CA conditions for a period of six months. Further were exposed to ambient conditions at 2^0C for two weeks. Ethylene production and firmness were measured. They found a correlation between ethylene production and pectin related enzyme activity.

Gwanpua et al. (2013) [21] Conducted experiments to study the variability from fruit-to-fruit and modelled the firmness during postharvest storage. Three cultivars, viz. Jonagold, Braeburn and Kanzi were stored at different CA and temperature conditions. Kinetic model was used to describe the firmness breakdown with respect to time, CA and

temperature conditions and ethylene concentration. Rate constants were calculated for firmness and ethylene production. Fruit-to-fruit variation was simulated using Monte Carlo method for the flesh firmness within a batch of apples. Independent data sets were used for validation of models for different season apples. This model can be used to predict certain firmness after storage

Gwanpua et al. (2016) [22] Studied an apple variety ‘Kanzi’ which is a cultivar recently developed, which got a low ethylene production and expected to be maintaining crispiness during ripening. They studied the behaviour of slow softening by comparing the tissue fracture pattern and pectin biochemistry. They also compared Kanzi with a rapid softening variety, Golden Delicious. Substantial depolymerisation of pectin and solubilisation were observed in golden delicious, Kanzi apples had no depolymerisation or increased solubilisation during ripening. Cell separation was responsible for tissue failure during ripening in Golden Delicious, where as tissue failure was due to cell breakage in Kanzi apples. Kanzi apples had a sudden firmness decrease and the reason is not tissue failure, but cell breakage.

Harker et al. (2006) [23] have studied the relationship between Penetrometer test and single edge notched bend (SENB) test to assess the fruit quality. Cox’s Orange Pippin, Sciearly, Sciros and Scifresh cultivars were stored in a cold storage and removed at regular intervals to assess the texture after 1 and 7 days at 20^0C. Measurement of texture was done with the Efegi Penetrometer puncture test and SENB test. A notched beam of tissue of apple was tested by three point bend test till breakage. Fracture toughness and fracture energy were calculated and examination done with low temperature scanning electron microscopy (LTSEM) for fracture surface during a beam failure. A correlation was made for fracture roughness and fracture energy with puncture force. Sciros and Sciearly had the higher fracture toughness and fracture energy. They also studied on the non-shriveled and shriveled Sciros apples and compared with puncture measurements and found that when the fruits are dehydrated, the puncture tests are unreliable. Puncture test shown shriveled apples as ‘crisper’, where as SENB parameters indicated reverse results compared to puncture measurements.

Konopacka and Plocharski (2004) [24] carried out experiments to find the relationship between the firmness of apples and sensory texture acceptability with respect to different storage atmospheres. Elstar, Jonagold and Gloster cultivars were stored at 3^o C in normal atmosphere, CA (with 5% CO_2 and 3% O_2) and low oxygen CA (with 1.5% CO_2, 1.5% O_2). Firmness of apples was varied by further storing at 0^oC and/or 18^oC for different periods. Magness-Taylor tests and sensory tests were conducted. They found a distinct effect of conditions of storage on the relationship between the firmness and fruit texture acceptability. This effect depended on the cultivar of apple. Higher values of firmness and wider & high firmness acceptability was found in Jonagold and Gloster apples in CA conditions compared to normal atmosphere apple storage. In case of Elstar apple, these kind of differences were not observed.

Lahaye et al. (2018) [25] conducted experiments to study mechanical properties based on water and cell wall contributions. Viscoelastic properties of apple cortex, water dynamics, chemical and histological characteristics were investigated. Four apple genotypes were studied for water mobility using low field NMR relaxometry. Results indicated the ability to discriminate genotypes by both methods of relaxation curve decomposition.

Springael et al. (2018) [26] harvest losses during transportation due to vibrations, routing and delays. An innovative approach was used by them to reduce the loss rate of apples. Proper planning or routes of transport was done. The loss rate of apples due to transportation vibrations was calculated. They have characterized the road types with respect to shock and vibrations. Optimal transport routing is done. Suggested that significant amount can be saved yearly when routes are planned properly. Results suggested for increased profit to growers and effective use of natural resources.

Thewes et al. (2015) [27] compared the effect of Dynamic Controlled Atmosphere (DCA) to Ultra Low Oxygen (ULO) on the quality of two apple varieties, i. e. Royal Gala and Galaxy after long term storage. Experiments were carried out in two seasons. Higher internal concentration of ethylene was reported in apples in CA. Fruits in ULO had intermediate ethylene concentration. Lowest ethylene concentration was observed under DCA-CF (DCA based on chlorophyll fluorescence). Higher flesh firmness was reported in DCA-CF and ULO compared to CA.

Varela et al. (2005) [28] Studied about the apple texture deterioration in Fuji apples stored in cold storage. The storage resulted in mealiness and softness. On 7 months storage under refrigeration (1^oC) in a CA with 2% O_2 and 2% CO_2, they have estimated the shelf life of apples kept at 20^0C in normal atmosphere till apples are consumed.

Shelf life was estimated using the methodology of survival analysis. The focus is on the shelf life hazard is the key concept with respect consumer rejecting the apple rather deteriorating of apples. The shelf life estimate of Fuzi apple was 23 days with 50% probability of rejection and 17 days with 25% probability of rejection. They found that quality loss is greater with increased mealiness, alcoholic taste, ripe taste and odour. The acceptability test and Thiault index showed that apples from cold storage were barely acceptable.

Wijewardane and Guleria (2011) [29] conducted experiments on freshly harvested apples cv. Royal Delicious. Apples were coated with different neem oil concentrations and different percentages of marigold flower extracts and are further subjected to pre-cooling and storage studies. Apples were analysed for physio-chemical and physiological characteristics (Firmness, pH, Titrable acidity, reducing sugar content, pectin, Total soluble solids, pectin, total anthocyanin, fruit spoilage and polygalacturonase). The results showed that that neem oil with 1.5 to 2% concentration as coating along with pre-cooling was most effective. Apples retained better physio-chemical characteristics and lower disease incidence.

MATERIALS AND METHODS

Controlled Atmosphere Store

The features of the CAS are: i) Temperature control (-2 to 15^0C), ii) Relative Humidity control (90-95%), iii) Air movement control, and iv) Oxygen, Nitrogen, Carbon di-oxide, and Ethylene level control. CAS extends storage life of fruits and vegetables in the range of minimum 3 months to maximum 8 months, depending on genotype, origin, variety, pre-harvest and post harvest practices and optimum storage parameters [15, 30]. Several Controlled atmosphere storages are constructed in India. CA Storage units in Delhi, Haryana and Gujarat are running successfully for the produce like apples, pears, oranges, kinnow, pomegranate, etc. since past 10 to 12 years. This study has been undertaken at the CA storage complex at Rai, Haryana, which is being the first largest commercial CAS in India. This storage unit was built in technical collaboration with International Controlled Atmosphere, UK under the guidance of David Bishop [11]. There is further large scope for constructing these kind of advanced CA storage facilities in India, being a developing country. Fruit firmness tests were performed to monitor the health of the fruits during storage were done as per the procedure prescribed by Bishop [11, 31].

In the CAS facility where present studies conducted, there are 78 controlled Atmosphere Storage chambers. All the chambers are of equal size and capacity. The chambers are made with sandwiched PUF (poly urethane foam) panels. The floor is insulated and top layer coated with epoxy. The evaporator with cooling fans is provided near the roof of the chamber. Each chamber contains separate cooling evaporator. The refrigeration systems (Bitzer screw compressors

with R404A direct expansion) are centralized. The temperature and Relative humidity (RH) are maintained based on the product stored. Apples are stored at 0^oC to 1^0C. RH is maintained between 90 to 95% to reduce the moisture loss from the fruits. Sensors are provided to measure the temperature at 4 locations. The return air temperature, product temperature by inserting probes into apples in two bins placed at extreme opposite corners of the chamber.

Uniform temperature is maintained throughout the holding period by maintaining 0.5^0C temperature difference between any two points in the chamber by a precise Programmable logic controller system (Carel, Italy). Oxygen content in the chamber is lowered by flushing the nitrogen made in the Pressure swing adsorption nitrogen generator with carbon molecular sieves (Carbotech, Germany). Excess carbon di-oxide and ethylene liberated from the apples are absorbed by a Carbon di-oxide scrubber containing activated alumina and carbon molecular sieves (Storage control systems, USA) [32]. Gas tightness of the chamber to maintain the desired gas composition is achieved by applying the elastic paint (Ribbstyle, The Netherlands). Oxygen and carbon di-oxide levels were monitored and controlled by Oxygen and CO_2 analyzer (ICA, UK). Gas composition was cross checked frequently using portable Oxygen and CO_2 Analyzer (ICA, UK) as prescribed by Bishop [11].

The dimensions of each storage chamber are 10 m x 9 m x 8 m (Length x Width x Height). Stacking of the bins is done using electric forklift or stacker. The size of the chamber door is 5.5 m x 4.5 m to accommodate easy movement of forklift truck to enter the chamber and quick loading and stacking of bins in the chamber. The Capacity of each chamber is 500 bins of 300 kg each.

Apples were procured from well maintained orchards situated at an elevation of 2700 meters above mean sea level in a village Chini (Kalpa of Kinnaur district) of Himachal Pradesh. Well grown, uniform, 15-20 year old apple trees raised on seedling rootstocks, were selected for harvesting and further storage studies. The trees were maintained under a uniform schedule of cultural operations. Rightly matured fruits were harvested manually and sound fruits of large, medium and small size were selected for conducting the studies [30, 33]. The fruits were packed in CFB boxes with paper moulded trays and were immediately transported to the postharvest physiology laboratory at CA Storage complex, Rai, Haryana, India for pre-storage operations and storage. Figure 1 below shows various steps involved in Apple handling.

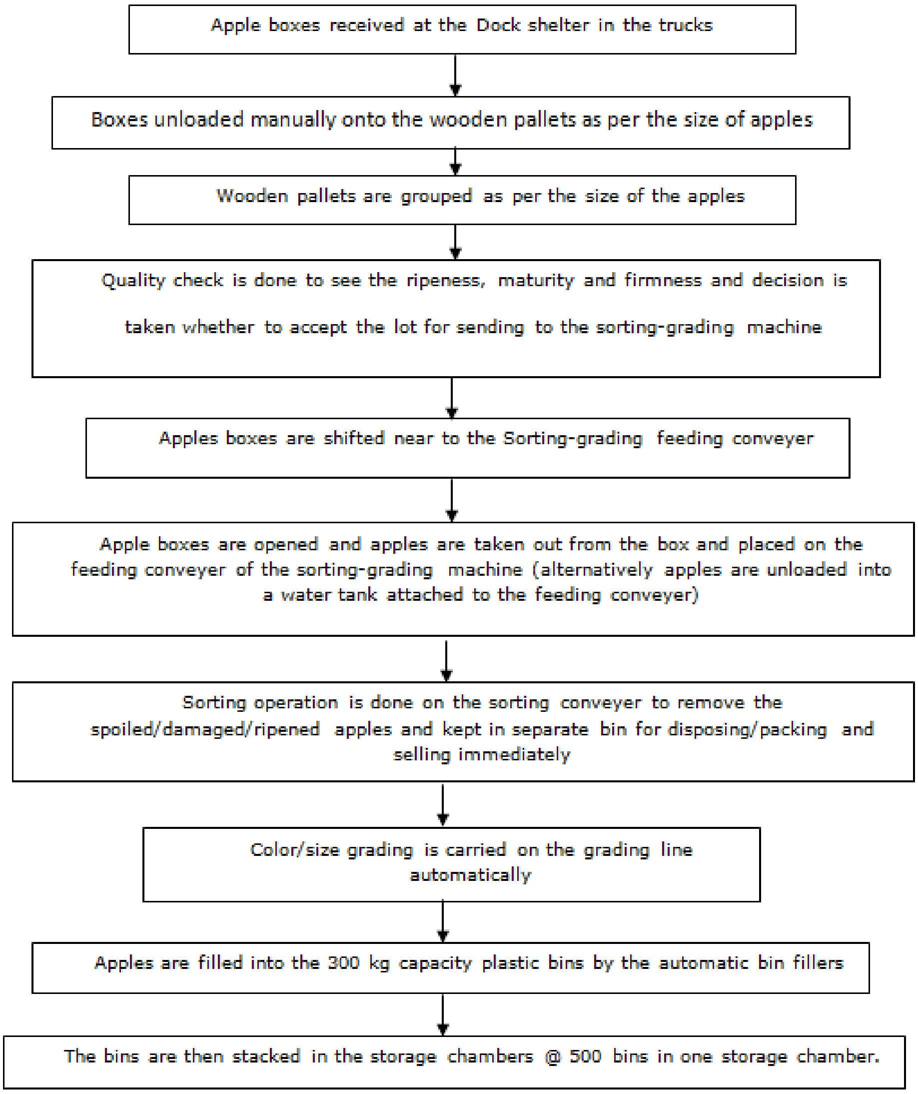

Figure 1: Flow Chart of Apple Handling

SORTING-GRADING MACHINE

This machine is used for sorting and grading of round shaped fruits. The capacity of the machine is 10 MT per hour. Four bin fillers are provided to fill four bins (of 300 kg capacity) simultaneously. A 5th exit is provided for cull fruit/non-categorized fruits. The machine is equipped with sensors for automatic fruit movement on conveyers, grading and bin filling. The manufacturer of the machine is M/s Sammo, Italy with grading software from M/s Ellips, The Netherlands.

The colour grading is done based on Hunter colour scale L, a, b and hue. Apples are sorted-graded with a machine vision system [34] with Hunter scale L, a, b, hue and saturation.

The features of the sorting - grading machine are:

- Facilities for washing, wiping, sorting, colour grading, size grading and bin filling
- Computerized programs with colour and size grading algorithms
- Apple Sorting & Refilling Lines into Bins

- Fruit that can be sized are: Apples, peaches, tomatoes, guava, kinnow, etc.
- Average fruit weight: 140 gm
- Minimum fruit diameter: 30 mm; Maximum diameter 110 mm.
- Connectivity with feeding system: Field containers: Plastic or wooden boxes 15-20 kg or similar (400x 600x 300). Wooden or plastic bins 1200 x 1000 x 750 or similar.
- Feeding capacity : 10 Tons/h
- Grading capacity: 80,000 fruits/h.

Size Grading

The size grading system measures the properties of the apple, for which the contour and stalk and calyx of the product are used. The measurements are taken accurately by viewing the product from various angles. The multiple images are taken for the apples. Measurement of the diameter, length, and surface area are calculated. Defects in shape can also be detected and in addition we can detect when two products are positioned in one cup. While rotating ten images are made of each product. In the EllipsTrueSort Software Imperial units or Metric Units can be selected for Weight and Size classes. Diameter is calculated with an accuracy of 0.1 mm.

Colour Grading

The colour of the fruit is highly representative of the quality and ripeness of the fruit. Using the colour module, based on live feedback from the cameras – determine the colour to grade the fruit (for example, the percentage of blush on an apple). Images from multiple cameras at various angles are combined in order to view the entire surface. The characteristics of the apple, therefore, are calculated. Ultrafine colour separations are obtained through software that enables operators to quickly create or modify the colour spectrum[40,41].

Unloading of Apples

In the existing system workers are instructed to transfer apples gently to avoid any bruising, but still some bruising occurs. Fruits are taken out of the 20 kg CFB boxes and loaded manually on to the conveyer of the machine. During this quick manual dumping of apples onto the conveyer will damage the fruit surface, and leads to reduction of shelf life during storage.

Water Unloading System

A water tank is designed and fixed at the existing feeding conveyer of the sorting-grading machine. For the purpose of conducting experiments, plastic storage bin of one cubic metre is used. Perforations of the plastic bin are covered using a thick polyethylene tarpaulin. Apples, after unpacking from the CFB boxes are transferred to this water tank manually. The slanting/inclined roller conveyer picks the apples and further sends to the sorting-grading line. In the existing system the workers transfer the apples from the CFB cartons to the sorting conveyer directly, during which mishandling occurs, leading to mechanical surface damages, and scratches on the surface of the apples. This is undesirable for long term storage[38].

The new water unloading system in the water tank can eliminate these kind of mechanical damages while transferring apples from CFB boxes to the sorting-grading machine. In the new system apples can be quickly unloaded to the water tank, where water acts as a cushioning medium for smooth handling of apples.

The apples after sorting-grading are subjected to controlled atmosphere storage. Each of the varieties of apples is kept in separate chambers considering different respiration and ethylene generation rates. This is done to avoid the varietal effect on the ripening behaviour and thereby firmness, loss [11, 35-36]. Four apple varieties were selected for this study, viz Royal delicious (RD), Red delicious (RED) and Rich-a –Red (RR) and Golden Delicious (GD)[39]. Apple sizes in India are traditionally termed as 100 count (Large), 125 count (medium), 150 count (small), 175 count (Extra small), 200 count, 240 count (Extra extra small) and 310 count (pittoo); Count indicates the number of apples in a 20 kg CFB box. Another size 80 count is also supplied from orchards, however, it was found from the preliminary experiments that it is extra-extra large and highly not suitable for storage. Size 100 indicates largest size and size 310 indicates smallest apples stored. Only large, medium and small sizes were chosen for this study, as these are prone to mechanical bruising easily compared other smaller sizes based on the preliminary studies about the bruising. These sizes were comparatively larger out of several size categories supplied from the orchards. The sorted-graded bins are shown in Figure 2. Sample of heavily bruised apple is shown in Figure 3.

Figure 2: Apples Filled in the Bins Gradewise after Sorting-Grading Operation

Figure 3: Sample of Bruised Apple

MEASUREMENTS

Measurement of Firmness

Firmness is measured using a Penetrometer (Model FT327) [37]. Firmness is expressed in pounds/Lbs. The relevant instrument is shown in Figure 4.

Lots of different orchards were kept in separate bins suffixing numerical identification to the size (Example: Large 1, Large 2, Large 3). Different sized apples of particular variety were kept in separate bins in the same chamber. However, different varieties were kept in different chambers.

Firmness is checked for six samples from each lot before and after storage. Peel was removed before measuring flesh firmness. This is done with a standard peeler supplied with the Penetrometer. Size specification of apple (diameter in mm) is as follows:

Large: 100 count-75 to 80mm, Medium: 125 count-70 to 75mm, Small: 150 count-65 to 70mm

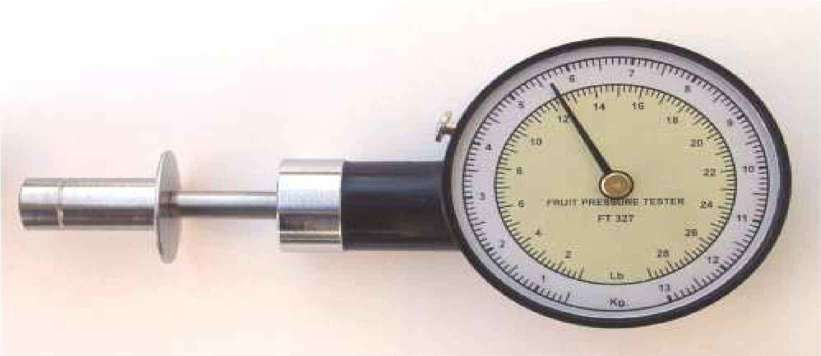

Figure 4: Penetrometer for Measurement of Firmness of Apples

RESULTS AND DISCUSSIONS

From Figure 5, firmness details of Royal Delicious can be seen. The highest firmness drop was found in 'Large 1' apples of manually handled the lot after storage for two months. Large1 apples with initial firmness of 18.5 Lbs decreased to 13.5 Lbs (5 Lbs drop) with manual unloading, whereas fruits of the same lot handled using water unloading had a firmness of 17.5 Lbs (1 Lbs drop) on post storage. For large 2, Large 3, the firmness drop found to be were 4.25 Lbs, 0.25 Lbs and 4 Lbs, 1Lbs for Manual and water handling respectively. For Medium apples the drop range is 3.75 Lbs to 4.5 Lbs and 0.5 Lb to 1 Lb for manual and water handling respectively. In case of Small apples, the drop is in the range of 1.75 Lbs to 2.25Lbs and 0.75 Lbs to 1.25Lbs for manual and water handling respectively. All the results indicated a significant reduction of apple softening with apple undergone water handling system. This indicates a better firm and crunchy apples.

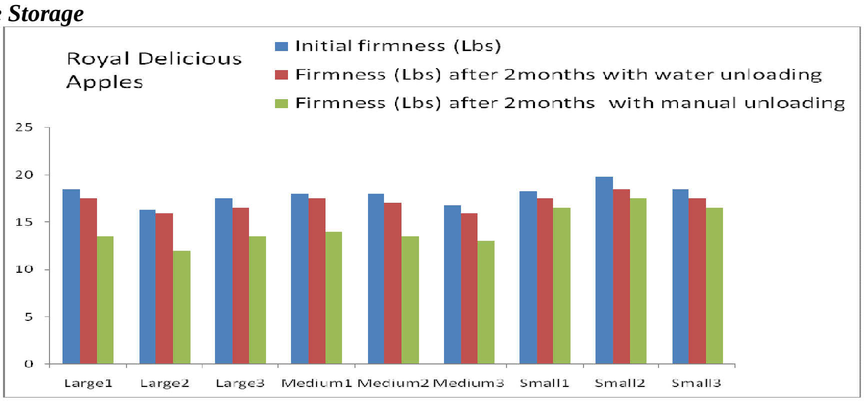

Figure 5: Effect of Handling Technique (Manual Unloading vs Water Unloading) on Firmness Values of Large, Medium and Small Apples (Royal Delicious) after Two Months of CA Storage. Different sized and orchard source Apples on X axis and Firmness in Lbs on Y axis

Figure 6 shows the data of Red Delicious apples. Firmness loss of three different orchard's 'Large' apples is in the range of 4 Lbs to 4.5 Lbs and 0.5 Lbs to 1.5 Lbs for manual and water handling respectively. In case of 'Medium' apples the drop is in the range of 2.5 Lbs to 2.75 Lbs and 0.25 Lb to 1.25 Lbs for manual and water handling systems respectively. Small apples also showed the same trend with drop range of 2.5 Lbs to 4.25 Lbs and 0.5 Lb to 1.5 Lbs for manual and water handling respectively.

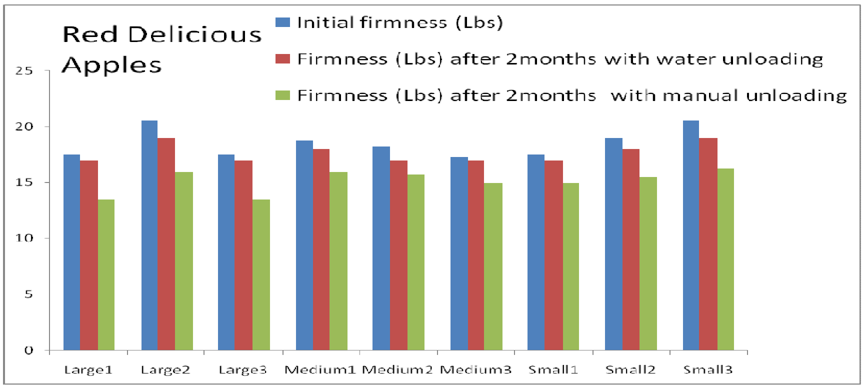

Figure 6: Effect of Handling Technique (Manual Unloading Vs Water Unloading) on Firmness Values of Large, Medium and Small Apples (Red Delicious) after Two Months of CA Storage. Different Sized and Orchard Source Apples on X Axis and Firmness in Lbs on Y Axis

Data pertaining to Rich-a-Red variety is given in Figure 7. The highest firmness drop was found in Large size apples compared to medium and small sized apples. Firmness drops among manually handled apples were in the range of 4 Lbs to 5.5 Lbs, 2.5 Lbs to 4 Lbs and 2.75 Lbs to 3.75 Lbs for 'Large', 'Medium' and 'Small' sized respectively. Water handled apples showed the drop was 0.5 Lb to 1 Lb, 0.5 Lb to 1.5 Lbs and 0.25 Lbs to 1Lbs for 'Large', 'Medium' and 'Small' sized apples respectively. This indicates better firmness in case apples passed through the water handling system.

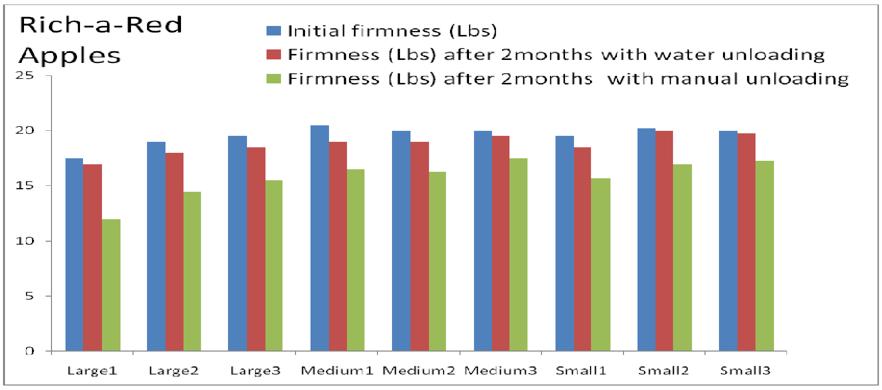

Figure 7: Effect of Handling Technique (Manual Unloading Vs Water Unloading) on Firmness Values of Large, Medium and Small Apples (Rich-a-Red) after Two Months of CA Storage. Different Sized and Orchard Source Apples on X Axis and Firmness in Lbs on Y Axis

Figure 8 gives the date of firmness, loss of Golden Delicious apples. Highest firmness drop found in Large apples compared to medium and small. The firmness loss with manual handling were 3.75 Lbs to 5.75 Lbs, 3.25 Lbs to 5.5 Lbs and 2.75 Lbs to 4.75 Lbs for Large, Medium and small apples respectively. Water handled apples had a firmness loss of 0.25 Lb to 0.5 Lb, 0.5 Lb to 1 Lb and 0.5 Lb to 1 Lbs for Large, Medium and small apples respectively.

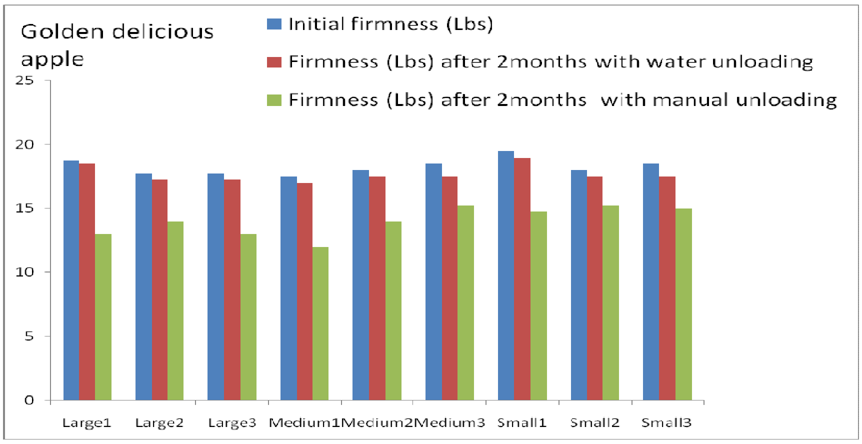

Figure 8: Effect of Handling Technique (Manual Unloading vs Water Unloading) on Firmness Values of Large, Medium and Small Apples (Golden Delicious) after Two Months of CA Storage. Different Sized and Orchard Source Apples on X Axis and Firmness in Lbs on Y Axis

Figure 9 indicates the net firmness loss of RD apples. The calculated percentage firmness loss in 'Large' was in the range of 22.8 to 27.0 and 1.5 to 5.7 for manual and water handling respectively. The percentage loss in 'Medium' apples was in the range of 22.2 to 25 and 2.7 to 5.5 for manual and water handling respectively. For 'Small' apples the percentage changes were 9.5 to 11.3 and 4.1 to 6.3 for manual and water handling respectively.

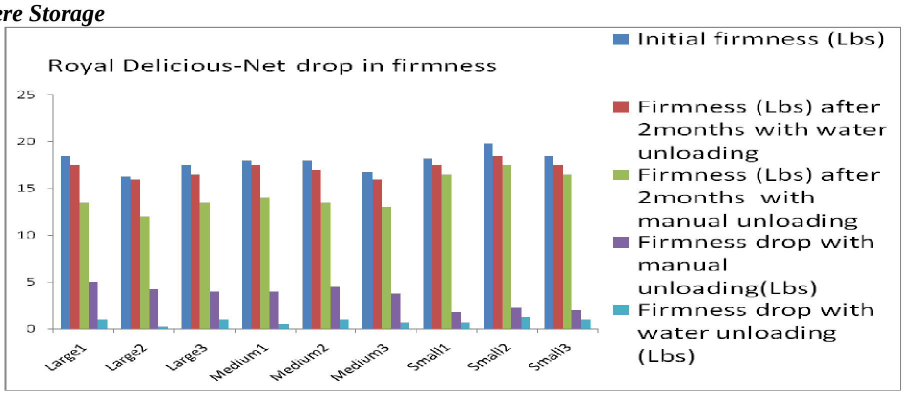

Figure 9: Net Drop in Firmness of Large, Medium and Small Apples (Royal Delicious) after Two Months of CA Storage. Different Sized and Orchard Source Apples on X Axis and Firmness in Lbs on Y Axis.

Figure 10 shows the net firmness loss of RED apples. The firmness loss calculated in percentage for 'Large' were 21.9 to 22.8 and 2.8 to 7.3 for manual and water handling respectively. For 'Medium' apples it is 13.0 to 14.6 and 1.4 to 6.8 for manual and water handling respectively. 'Small' apples dropped by 14.2 to 20.7 and 2.8 to 7.3 for manual and water handling respectively.

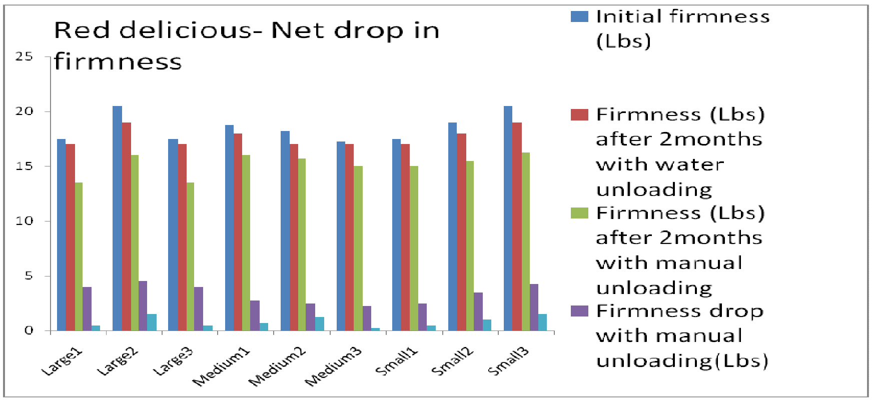

Figure 10: Net Drop in Firmness of Large, Medium and Small Apples (Red Delicious) after Two Months of CA Storage. Different Sized and Orchard Source Apples on X Axis and Firmness in Lbs on Y Axis

Figure 11 shows the net firmness loss of RR variety. The calculated percentage firmness loss in 'Large' was in the range of 20.5 to 31.4 and 2.8 to 5.2 for manual and water handling respectively. For 'Medium' apples the same were 12.5 to 19.5 and 2.5 to 7.3 for manual and water handling respectively. Small apples had a loss of 13.7 to 19.2 and 1.5 to 5.1 for manual and water handling respectively.

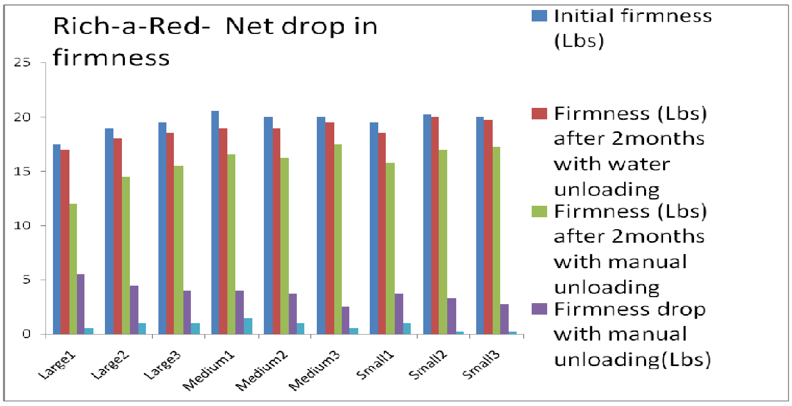

Figure 11: Net Drop in Firmness of Large, Medium and Small Apples (Rich-a-Red) after Two Months of CA Storage. Different Sized and Orchard Source Apples on X Axis and Firmness in Lbs on Y Axis

Figure 12 shows the net firmness loss of GD variety. The calculated percentage firmness loss in Large was in the range of 21.1 to 30.6 and 1.3 to 2.8 for manual and water handling respectively. For 'Medium' apples the same were 17.5 to 31.4 and 2.7 to 5.4 for manual and water handling respectively. Small apples had a loss of 15.2 to 24.3 and 2.5 to 5.4 for manual handling and water handling respectively.

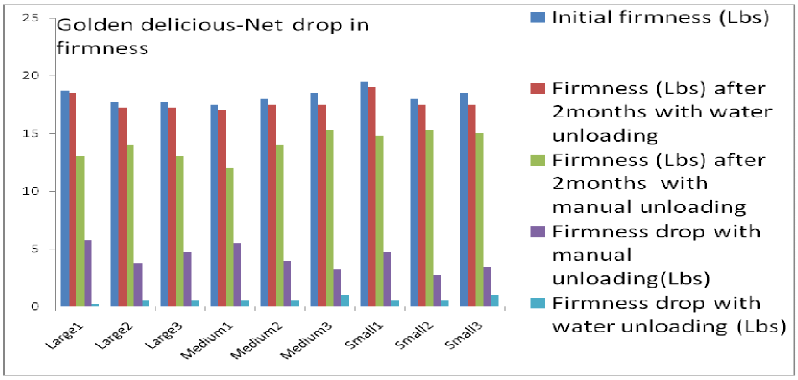

Figure 12: Net Drop in Firmness of Large, Medium and Small Apples (Rich-a-Red) after Two Months of CA Storage. Different Sized and Orchard Source Apples on X Axis and Firmness in Lbs on Y Axis

Table1: Comparison of Net Firmness Drop with Respect to Variety, Size, Orchard Source and Handling Technique after Two Months CA Storage

Variety--	Royal Delicious		Red Delicious		Rich-a-Red		Golden delicious	
Apple Size	Manual unloading (Lbs)	With water unloading (Lbs)	Manual unloading (Lbs)	With water unloading (Lbs)	Manual unloading (Lbs)	With water unloading (Lbs)	Manual unloading (Lbs)	With water unloading (Lbs)
Large1	5	1	4	0.5	5.5	0.5	5.75	0.25
Large2	4.25	0.25	4.5	1.5	4.5	1	3.75	0.5
Large3	4	1	4	0.5	4	1	4.75	0.5
Medium1	4	0.5	2.75	0.75	4	1.5	5.5	0.5
Medium2	4.5	1	2.5	1.25	3.75	1	4	0.5
Medium3	3.75	0.75	2.25	0.25	2.5	0.5	3.25	1
Small1	1.75	0.75	2.5	0.5	3.75	1	4.75	0.5
Small2	2.25	1.25	3.5	1	3.25	0.25	2.75	0.5
Small3	2	1	4.25	1.5	2.75	0.25	3.5	1

Table 1 shows the net firmness loss of apples with respect to size, variety and handling technique. Numerical suffix for each size indicates apples harvested from different orchards. (for example Large 1, Medium 3 and Small 2 etc.). In all the cases, the overall firmness loss is significantly reduced with water handling system. In case of manual handling, highest firmness loss in 'Large' apples were 27.02% (Large 1), 22.85% (Large 1), 31.42% (Large 1) and 30.66% (Large 1) for Royal Delicious, Red Delicious, Rich-a-Red and Golden Delicious respectively. In case of water handling system, highest firmness loss for 'Large' apples were 5.7% (Large 3), 7.3% (Large 2), 5.2% (Large 2) and 2.8% (Large 2) for Royal Delicious, Red Delicious, Rich-a-Red & golden Delicious respectively. Highest firmness loss is observed in a Golden Delicious variety of Large apples. This may be due to high ethylene production and ripening behaviour of Golden Delicious. Similar kind of results were also reported by Gwanpua et al. (2016) [22] for Golden delicious and they have referred this as rapid softening variety. Similar kind of results obtained for the apples of all three orchards for the same size category of apples, which are indicated as Large 1, Large 2 and Large 3. When compared size-wise, there is no definite trend in net firmness loss.

CONCLUSIONS

Apples when transferred to the water in a tank connected to the sorting-grading machine found retained with better firmness compared to the apples handled without water handling system. The proposed system will help in better shelf life through firm apples.

Use of water handling system has significantly reduced the firmness loss in different varieties of apples. In case of manual handling, highest firmness loss was found to be 27.0% (Large 1), 22.8% (Large 1), 31.4% (Large 1) and 30.6% (Large 1) for Royal Delicious, Red Delicious, Rich-a-Red & Golden Delicious, respectively. In case of water handling system, highest firmness loss for 'Large' apples are 5.7% (Large 3), 7.3% (Large 2), 5.2% (Large 2) and 2.8% (Large 2) for RD, RED, RR and GD respectively. Among varieties, highest firmness losses were observed in Golden Delicious apples.

It may be concluded that, use of water handling system reduced the firmness loss significantly irrespective of varieties. The experiments conducted paved a way to sensitize the requirement of gentle handling of apples during sorting-grading operations before storage. It is also evident that apples handled smoothly and gently before storage resulted in better textured apples, which is a very important and desirable characteristic of eating quality of apple. Further investigations could be taken up to cool the water of the water tank, so that pre-cooling and gentle handling will take place simultaneously.

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